PRINCIPLES OF TIME-MEASURING APPARATUS[1]

I.

WE cannot measure time in that sense in which we measure other things. Time has been very happily defined as the great independent variable of all change; and it is by watching matter in motion, which is the simplest form of change with which we are acquainted, that we estimate its progress. Thus, the motion of the earth around its axis furnishes us with that well-defined interval, the day; and the motion of pendulums (which swing against the earth's attraction) and of watch balances (which swing against the attraction of the particles of matter of which their springs are composed) furnish us with its subdivisions. I mention this at starting, because during our discussion, I want you perpetually to bear in mind that pendulums and watch balances are not mere appendages or terminations to the mechanism of time-measuring apparatus, but are themselves the true time-measurers; and in general, the question of accurately constructing such apparatus resolves itself into the problem of obtaining an uniform impulse—just such an impulse, neither more nor less, which shall exactly restore to the pendulum or watch balance that amount of motion, of which it has, during its preceding swing, been deprived, by the friction of its connections, and the resistance of the atmosphere.

Our natural time-measures, the sidereal and solar days, are determined respectively by the passage of a star or the sun across the plane of the meridian. The solar day is three minutes fifty-six seconds longer than the sidereal day, the reason of which will be obvious from the accompanying diagram (see Fig. 1). During the

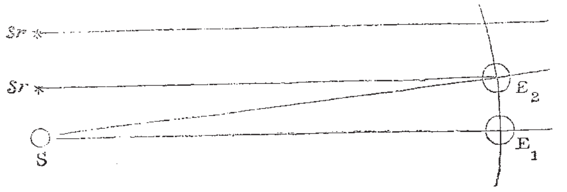

FIG. 1.

time of rotation, the earth, E, has advanced a little distance upon its annual journey round the sun, S. Therefore, any place upon its surface will have to proceed just a little further (through the angular space $Sr\,E_2\,S$) in order to get the sun opposite to it, than it would have had to have done, had the earth been stationary. The sidereal day is practically the time of one exact rotation of the earth upon its axis; the distance of the stars being so indefinitely great, that their rays throughout the width of the earth's orbit may be considered to continue parallel.

The measure employed in our ordinary every-day reckoning of time is mean solar time, which we derive in this way. Through sundry astronomical causes, the time of the earth's rotation with respect to the sun is not exactly uniform, solar days differing at certain periods of the year by as much as half an hour. In order to avoid the practical inconvenience which it would occasion by having days, hours, and minutes of different lengths, at different seasons, we add the time of all the days of the year together, and dividing by their number (which is fractional) we obtain the average length or mean of the days, and we refer to this and its sub-divisions as days, hours, minutes, of mean time.

Hour-glasses, candles, and water-glasses, were the instruments used by the ancients to indicate the passage of time. It was not till a comparatively recent date that apparatus consisting of a moving body, impelled through the medium of a combination of wheels (which also served to register the body's progress) was introduced for the purpose. We have a very good illustration of such early mechanism in the clock from Dover Castle (see Fig. 2).

A rope supporting at its extremity a weight, W, is wrapped around a cylinder or barrel, B, and by its means

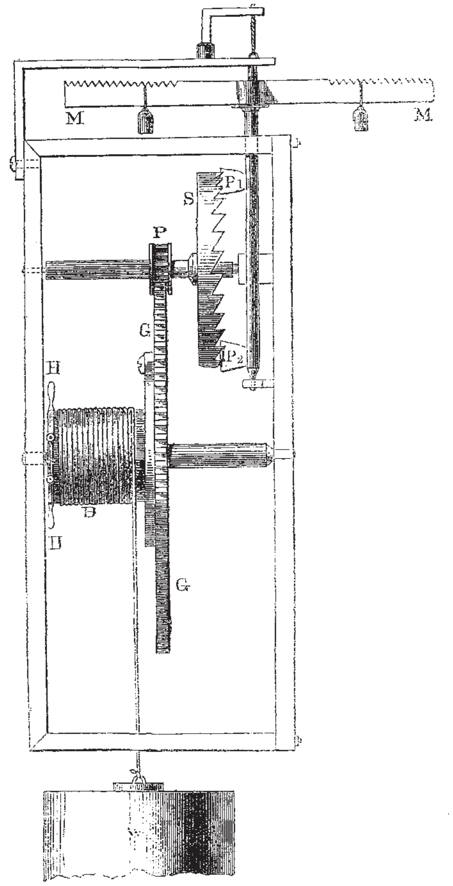

FIG. 2.

drives the wheel G G. This wheel is engaged with a pinion, P, and through it impels the escape-wheel S. The teeth of the escape-wheel operate upon two tongues or pallets, P_1 P_2, set at an angle to each other upon the stem carrying the moving body or time-measurer, M M. The

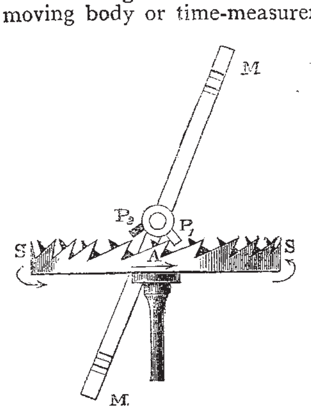

FIG. 3.

action of the wheel upon the pallets is exceedingly simple; the tooth A (see Fig. 3[1]) is now pushing the pallet P_1 to the right. It will presently have pushed it out of the way

[1] Lecture by Mr. H. Dent Gardner, a the Loan Collection, South Kensington.

[1] For comparison with Fig. 2, imagine the wheel to be moving in the reverse direction, and the letters P_1 P_2 interchanged.

B B 2

altogether, and then the tooth beyond upon the opposite side of the wheel will fall upon the other pallet, and a process similar will take place. By this arrangement the moving body, or balance, will alternately be driven backwards and forwards.

Prior to experiment, it is not easy to see why a contrivance such as this is should not go (in other words run down) with uniformity. We have a constant weight impelling a constant weight, and the contrivance itself destroys acceleration, but the fact is, we here overlook the great disturbance due to friction.

If we could indefinitely magnify each of the surfaces now in contact in this machine, we should see that what we call sliding and rubbing is (especially upon the pallets) in reality tearing and grinding, and the wonder would be, not that the motion produced is not equal and regular, but that it should have any tendency whatever in this direction.

No doubt the first steps towards equalising the motion

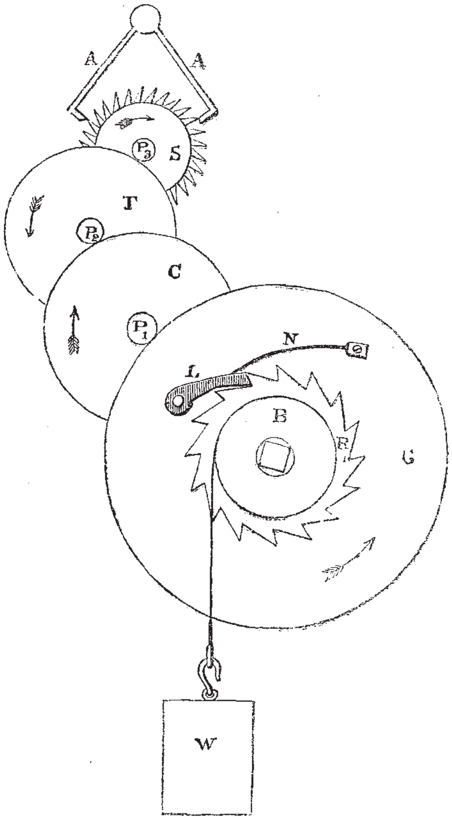

FIG. 4.

of such apparatus were in the direction of a general improvement in their workmanship and mechanical arrangement. Then came the fundamental ones of the pendulum for clocks and the pendulum spring for watches, and lastly, those in the arrangement of that mechanism (called the escapement) which modifies the manner in which the power of the clock weight is finally administered to the pendulum or balance.

It will be convenient to discuss these improvements not strictly in historical sequence; we shall begin with the machinery itself, or clock-train.

Trains.

Fig. 4 shows the general arrangement of a modern clock-train. G is the "great wheel" connected with the "barrel" B, around which the line carrying the weight W is wrapped. This great wheel drives a pinion, P_1, fastened upon the spindle of the centre-wheel C, and the centre-wheel in turn drives another pinion, fastened to the spindle of the third wheel T, and the third wheel again another upon the spindle of the escape-wheel S. The escape-wheel operates upon two arms or "pallets," A A, and by their means passes on impulse to the pendulum. For a clock with a seconds' pendulum there are generally thirty teeth in the escape-wheel, and as one tooth passes either pallet at every other vibration of the pendulum, you will see that it turns once in a minute, and its spindle carries the seconds' hand. The numbers of teeth in the escape-pinion, third wheel, third pinion, and centre wheel are so arranged that the centre-wheel turns once for every sixty turns of the escape-wheel, that is, once in an hour. The great wheel which engages the centre pinion turns once in twelve hours, and for an eight-day clock there are, of course, sixteen turns of the line upon the barrel.

Fig. 5 shows the apparatus for obtaining the relative motions of the hour and minute-hands. Upon the spindle S S of the centre-wheel (which you recollect turns once in an hour) is placed, friction-tight (that is, so stiff that it clings to the spindle, and yet loose enough to be movable by

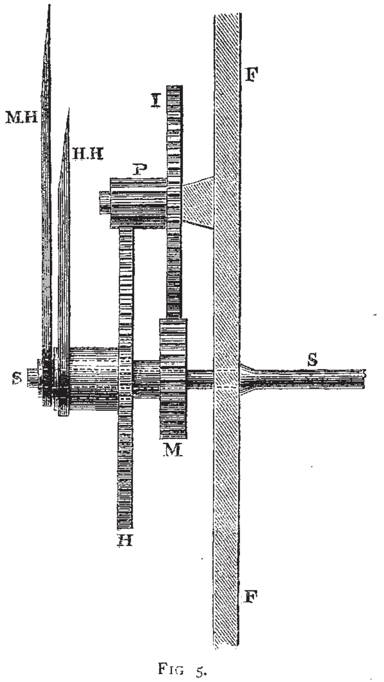

FIG. 5.

hand), the wheel M, with a long socket reaching through to the left which carries the minute-hand M H at its extremity. This wheel gears with another, I, which it moves round in twice its time, *i.e.*, in two hours. Connected with this second wheel is a pinion, P, and the wheel H (which rolls upon the socket of the wheel M), gears into it. This wheel is arranged to move round six times as slowly as the pinion P, that is to say, in twelve hours, and it carries a socket to which the hour-hand H H is attached. The socket-wheel, M, being on the spindle of the centre-wheel, only friction-tight, you can, of course, shift the combination without disturbing the clock-train.

The barrel, B, is connected with the great wheel by means of a ratchet-wheel and click (see Fig. 4). The ratchet-wheel, R_1, is fastened to the barrel, and when you wind up the weight by turning the barrel, its teeth being pointed backwards, pass under the click L. When you cease winding, the square face of the tooth meets the click, and communicates pressure through it to the great wheel.

But when you wind the clock, you relieve the great wheel from the strain of the weight, and the clock would stop if you did not introduce mechanism to prevent it. Fig. 6 represents such mechanism.

In this case the click L is fastened not upon the great wheel G G but upon an additional ratchet-wheel, $R_2 R_2$, which rides loosely upon the axis of the great wheel. Its

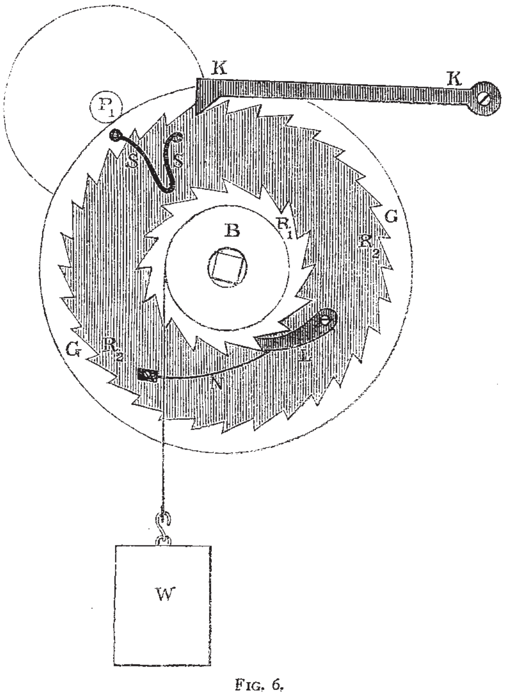

FIG. 6.

teeth, which point in the reverse direction to those of the first ratchet-wheel, pass under the long click K K mounted within the clock frame, and so far as the driving power of the clock weight is concerned, its action may be neglected altogether.

This ratchet-wheel is connected with the great wheel only by the spring S S, one end of the spring being fastened to the great wheel and the other to the ratchet-wheel. The strain of the clock weight keeps this spring closed and is transmitted to the great wheel through it.

Let us see what will happen when we try to wind. The spring S S is relieved from the strain of the weight and essays to open by thrusting back the ratchet $R_2 R_2$, but this it cannot do, for the long click K K prevents it, and banking against this the thrust of the spring is transferred to the clock-train.

Other mechanism is also employed for the purpose.

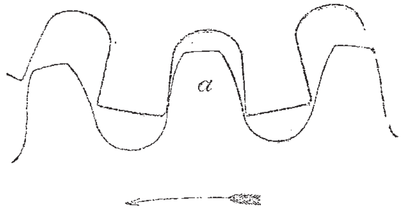

FIG. 7.

One very favourite plan (a very old one, which has been once or twice re-invented lately) places the fulcrum of the lever (in other words, the spindle of the wheel) through which the barrel is wound, upon the great wheel itself.

Great care has to be taken both in shaping and sizeing the various wheels and pinions. It is an advantage to have high numbered pinions, because in this case you do not get so oblique an action of the wheel teeth upon the teeth of the pinions: the action is more across the line of centres.

The curves of the teeth must also be properly formed. The broad principle is to get an uniform running, that is, that the pinion shall always move at a fixed and definite rate with regard to wheel, for if it moves faster or slower it is quite clear that the wheel tooth is acting too far up or too low down the flank of the pinion tooth, that is to say, working it at the end of too short or too long a lever; and less or more power is accordingly transmitted. If you look at Fig. 7 you will see easily that if the top of the wheel tooth *a* were not rounded off quite so much it (supposing the present curve correct) must drive the pinion too fast, and too little power would then be delivered.

Sometimes the main clock-train is merely employed to wind up at certain short intervals (usually twice a minute) a subsidiary weight or mainspring, which latter is that which immediately propels the escape wheel. In this manner variations in the friction of the clock-train can

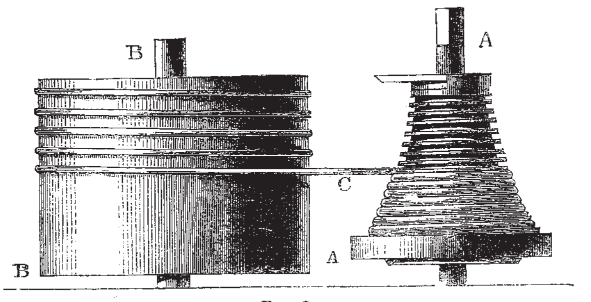

FIG. 8.

be in great measure prevented from reaching the pendulum, if there is a little less or more power upon the clock-train, the only effect being to wind up the subsidiary weight or spring more or less rapidly. The main clock-train is at the right moment liberated by some mechanism upon the spindle of the escape-wheel and the minute-hand being connected with it moves by jumps whenever the weight or spring is wound up.

The general arrangement of the train of watches and chronometers differs little from that of clocks, but the power is delivered by means of a coiled spring, which necessitates the following arrangement.

The spring pulls harder the further you wind it, and its force at commencing would be obviously greater than when it has in part run down; we therefore introduce the following compensation (see Fig. 8). We place the great wheel upon that hollow-sided cone or "fusee" A A, and connect it with the barrel B B (which is impelled by the main spring inside it) by means of a chain, C. When the spring pulls hardest it has the thinner part of the fusee to act upon, it works a lever of shorter radius, and the force at the circumference of the great wheel is in this manner equalised.

(*To be continued.*)

FLORIDA SHELL MOUNDS[1]

THE river St. John drains the eastern portion of the northern half of the peninsula of Florida, running northward over a flat country for a distance of about 300 miles. In the lower part of its course it opens out into large sheets of water two to three miles in width, and as might be expected from the nature of the country, it frequently shifts its bed, and is liable to annual inun-

[1] Fresh-water Shell Mounds of the St. John's River, Florida. By Prof. Jeffries Wyman. In the Memoirs of the Peabody Academy of Science. Vol. I. No. 4.